Optical & Thermal Analyses of High-Power Laser Diode Arrays

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Introduction

An important need, especially for space-borne applications, is the early identification and rejection of laser diode arrays which may fail prematurely. The search for reliable failure predictors is ongoing and has led to the development of two techniques, infrared imagery and monitoring the Temporally-resolved and Spectrally-Resolved (TSR) optical output from which temperature of the device can be measured. This is in addition to power monitoring on long-term burn stations. A direct measurement of the temperature of the active region is an important parameter as the lifetime of Laser Diode Arrays (LDA) decreases exponentially with increasing temperature[1]. We measure the temperature from time-resolving the spectral emission in an analogous method to Voss et al[2].

In this paper we briefly discuss the measurement setup and present temperature data derived from thermal images and TSR data for two differently designed high-power 808 nm LDA packages of similar specification operated in an electrical and thermal environment that mimic the expected operational conditions.

Experimental Description

The experimental setup for LDA characterization is shown in Figure 1. The LDA is mounted to a thermally controlled heat sink maintained at 25°C. The diode driver provides current pulses of up to 150A peak, between 50μs and 5ms duration, and a compliance voltage of up to 100V. The LDA drive current is monitored via a low-voltage current monitor built into the diode controller and DAQ card. Voltage across the diode is measured with digital multimeter. The light from the laser diode array is collected by an integrating sphere. The optical power is monitored with a UDT S390 power meter calibrated with this integrating sphere. In addition there is a fiber optic port which couples light to an Agilent 86141B optical spectrum analyzer (OSA). Time-resolved emission measurements are made with the OSA set to "filter-mode", a fiber-coupled photodiode and digital oscilloscope. In filter-mode the OSA acts as a narrow band-pass filter.

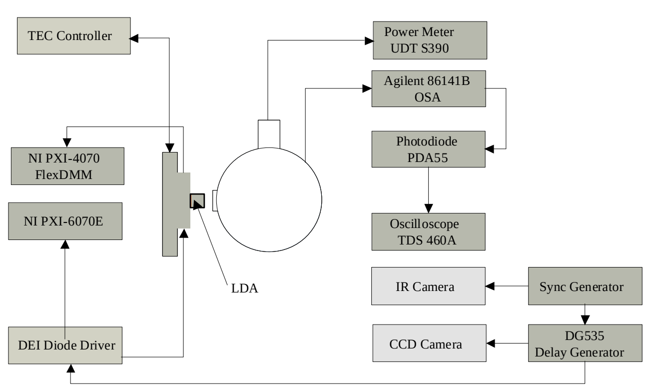

Figure. 1 Schematic of the measurement set up showing TSR instrumentation, MID-IR Camera and Near Field Camera.

Thermal images are captured in the 3 to 5 µm spectral region using a commercial mid-infrared camera. The camera has 320 x 256 InSb FPA (30 x 30 µm pixel size) with a frame rate of 60Hz and an integration time of 1.7msec. The MID-IR camera has germanium 1x microscope lens, which gives a spatial resolution, limited by FPA pixel size, of 30µm. Temperature resolution is better than 25mK. To correctly capture the IR pulses it is important to synchronize the MID-IR camera to the diode pulses. Both the diode driver and MID-IR CCD camera are synchronized to the same reference signal through a digital delay generator.

For near field images we use a commercial monochrome CCD camera. To avoid saturating the CCD it is necessary to attenuate the optical signal with ND filters.

Results and Discussion

Two high-power 808 nm, laser diode arrays with different mechanical package designs are measured and compared. Both devices are 4-bar arrays and each bar has ~70 emitters. The device under test was mounted on a temperature controlled heat sink, maintained at 25˚C and allowed to come to thermal equilibrium while operating at 70A peak current, in 200µs pulses at 30 Hz rep-rate producing approximately the same optical output power. The OSA was set to

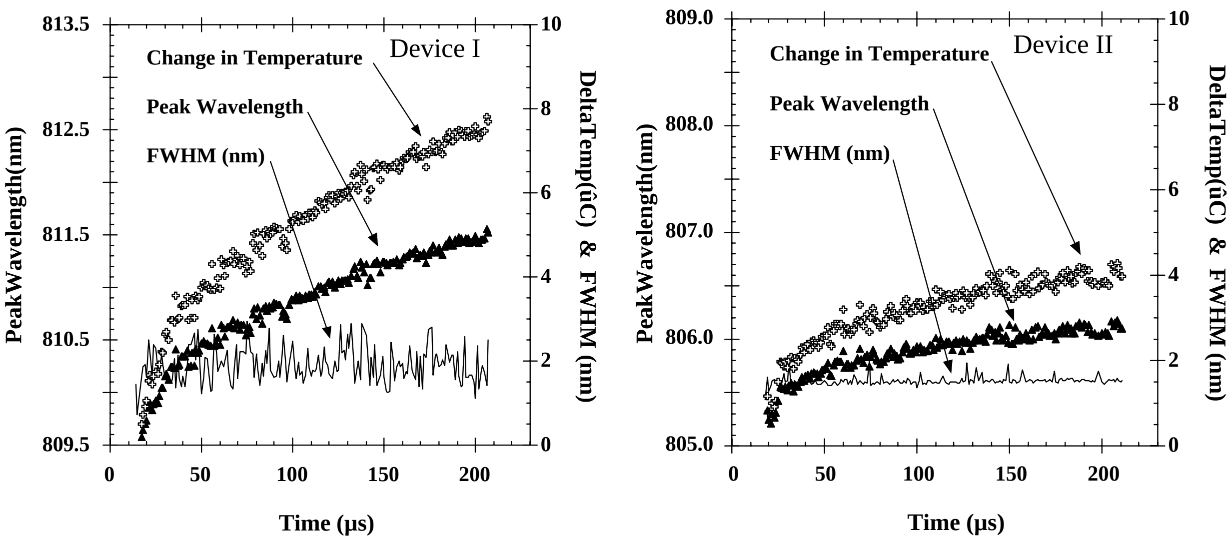

Figure 2. Change in temperature, peak wavelength and FWHM as a function of time.

filter mode and the center of the filter stepped through the emission spectrum of the LDA. At each wavelength-setting the temporal profile of the intensity is recorded via the digitizing oscilloscope. The resulting data matrix was then analyzed to determine the peak wavelength as a function of time. The peak wavelength of these LDAs tunes ~ 0.27nm/˚C. The peak wavelength, Full Width Half Maximum (FWHM) and temperature, derived from the temporally resolved data matrix, are plotted in Figure 2. This representation of the temporally resolved spectra clearly shows a temperature induced chirp to longer wavelengths. This chirp is attributed to the current pulse thermally tuning the device. The current pulse induces a bulk temperature rise of ~ +8˚C and a shift to longer wavelength of ~ 2nm by the end of the 200µs pulse in the Device I. An approximately +4˚C change and just over +1 nm shift are induced in Device II. After the first 30 µs the heating is linear with time consistent with a constant rate of heating. The spectral FWHM, to within the measurement (0.1 nm), does not change during the pulse.

Device II, under the same measurement conditions shows a much lower temperature rise, again with no discernable change in the spectral width. This LDA should, all other considerations being equal, have a longer mean-time between failures due the lower thermally induced stress[3]. Also studied was the temperature rise for different operational rep-rate but at the same heat sink temperature. Figure 3 plots the induced temperature rise derived from the wavelength chirp for 30, 60 and 90 Hz rep-rate. The temperature of the device was maintained at 25˚C and the peak current pulse increased to 100A. The temperature change due to the drive pulse is shown to be essentially independent of frequency for these low rep-rates. However the device may exhibit a slight bias to higher temperatures at higher rep-rates. The overall, larger, change in temperature, compared to figure 2 is due to the higher peak current.

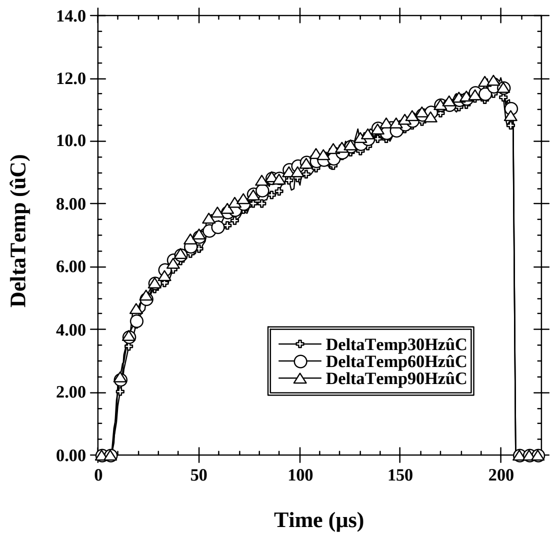

Figure 3. Plotted are the measured temperature change derived from the shift in peak wavelength at three rep-rates; 30 Hz, 60 Hz and 90 Hz.

It is important to note that all these data represent the spatially averaged output of all the laser diode emitters and thus the average temperature of all the active regions.

To spatially resolve the temperature, thermographic images of the LDAs were also recorded. The IR camera was used in an external synchronization mode. The sync' signal was a 29.97Hz square wave with 50% duty cycle. The camera was triggered on both the rising and falling edges of each pulse providing 59.94 frames per second operation. The diode driver was synchronized with the same signal but was triggered only on the rising edge operating at 29.97Hz. We acquired a stream of 32 frames from IR camera. Half of the frames in the stream captured the LDA while the current was applied to the diode, On-cycle thermograph images, and the other half captured LDA thermograph images while it was cooled down, Off-cycle images. Numerically the averaged Off-cycle images were then subtracted from the averaged On-cycle images. The subtracted image, figure 4, clearly shows a spatially resolved temperature rise of the LDA during each pulse. Correction for emissivity and relative duty cycle can be applied to the measurement to determine the temperature map of the LDA. One can clearly see the four bar construction of the devices. It also revealed the existence and locations of several hot spots not observed by TSR or nearfield image. Figure 5 is the nearfield image of the LDA array showing the array of individual laser emitters.

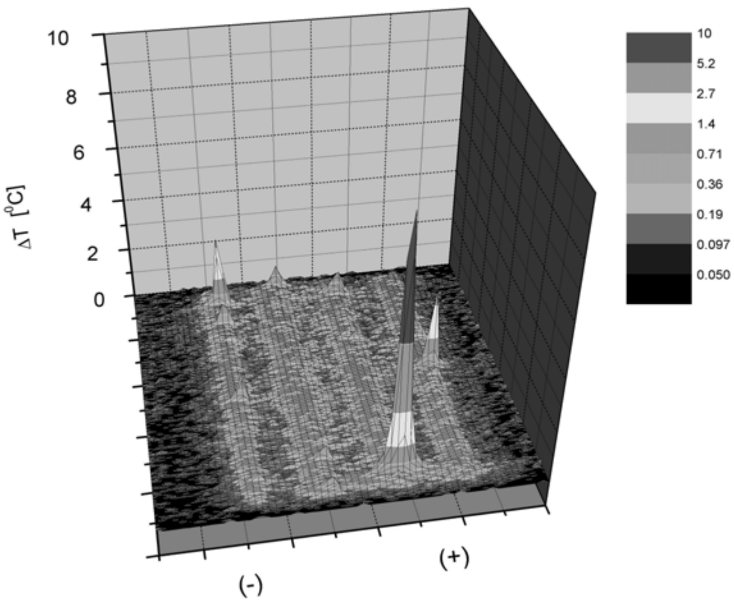

Figure 4. The 3-D thermographic image clearly illustrates hotspots.

Figure 5. Nearfield image of the laser diode array under normal operation.

Conclusion

From the temporally and spectrally resolved output from the LDA one can directly measure the increase in temperature of the active region of the LDA. These data are used with the thermographic images to measure the spatial distribution and magnitude of the temperature change. Infrared images taken in the 3-5 µm optical band can clearly show the presence of anomalous hot-spots within the normal thermal features of the array.

References

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